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Bioremediation: Panacea or fad?

Presenter: Dr. Brian R. Shmaefsky
Host: Gail Tucker
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Abstract

All things in nature ultimately succumb to decay. Much of this is a natural consequence of the laws of thermodynamics. Researchers developed bioremediation as one feasible way to accelerate or encourage the degradation of pollutants. The basis of bioremediation is that all organisms remove substances from the environment to carry out growth and metabolism. Bioremediation does not involve only the degradation of pollutants. Bioremediation can be used to clean unwanted substances from air, soil, water and raw materials for industrial processing. Technologies using bioremediation treatment include: Bioaugmentation, a general term describing the addition of organisms or enzymes to a material to remove unwanted chemicals. Biofilters, removal or organic gases by passing air through compost or soil containing microorganisms capable of degrading the gases. Bioreactors, treatment of a contaminated substance in a large tank containing organisms or enzymes. Biostimulation, the use of nutrients or substrates to stimulate the naturally occurring organisms that can perform bioremediation. Bioventing, involves the venting of oxygen through soil to stimulate the growth or natural and introduced bioremediation organisms. Composting, involves mixing contaminated materials with compost containing bioremediation organisms. Landfarming, the use of farming tilling and soil amendment techniques to encourage the growth of bioremediation organisms in a contaminated area. These technologies are classified as either in situ or ex situ. There are several limitations for using of bioremediation. One major limitation has to do with the nature of the organisms. Two other limitations concern cost and the benefits versus overall environmental impact. The question in the mind of many environmental scientists is, are the merits of bioremediation over-rated?

Introduction

All things in nature ultimately succumb to decay. Much of this is a natural consequence of the laws of thermodynamics. Many molecules degrade by the action of oxygen, halogens and radicals naturally found in the environment. A large proportion of materials degrade because their components are subject to the action of enzymes. Unfortunately for humans, many of the wastes that we produce do not decay as fast as we would like. They end up polluting the air, land and water. Two major factors prevent our wastes from decaying rapidly. One is that we produce so much at one time that the rate of natural decay is insignificant compared to the amount present. Another factor is that most wastes end up in areas not conducive to rapid degradation.

Researchers developed bioremediation as a way to accelerate or encourage the degradation of pollutants. Bioremediation is a term that describes the use of organisms to remove or reduce human-made pollution. The term bioremediation is new in the scientific vocabulary. In fact, the Environmental Protection Agency had to develop an absolute definition of the term for their purposes. The principles of modern bioremediation are not new, dating back to the 1960's. Some of the first studies on using microbes to degrade oil in sea water were conducted in 1972 although sewage treatment using rock filtration was the earliest application of bioremediation. Bacteria were encouraged to grow in these filters which broke down and absorbed organic matter before it reached a lake, ocean or river. At first bioremediation was a curiosity, today it is seen as a cure-all for up all types of pollution, including radioactive isotopes.

Principles of Bioremediation

Bioremediation is based on the idea that all organisms remove substances from the environment to carry out growth and metabolism. Bacteria, protista and fungi are very good at degrading complex molecules and incorporating the breakdown products into their metabolisms. The resultant metabolic wastes that they produce are generally safe and somehow recycled into other organisms. Fungi are especially good at digesting complex organic compounds that are normally not degraded by other organisms. The ability to degrade a pollutant is dependent on enzymes produced by the organism. Petroleum can be degraded only by bacteria with the ability to produce enzymes that select petroleum as a substrate.

Bioremediation does not involve only the degradation of pollutants. Sometimes it is sufficient to remove the pollutant from the environment without degrading it. Bacteria in particular take up large amounts of metals and minerals to ensure adequate resources for binary fission. Algae and plants are very good at absorbing nitrogen, phosphorus, sulfur and many minerals and metals from the environments. For example, plants like locoweed remove large amounts of the toxic element selenium. The selenium is stored in plant tissues where it poses no harm until/unless the plant is eaten. Many algae and bacteria produce secretions that attract metals that are toxic in high levels. The metals

are in effect removed from the food chain by being bound to the secretions.

Technology of Bioremediation

Bioremediation can be used to clean unwanted substances from air, soil, water and raw materials from industrial processing. Living organisms or just their enzymes can be used to accomplish this task. One unusual application involves the use of fungi to remove excess lignin from paper pulp. Lignin is not one compound, but, a group of polyaromatic chemicals that harden wood. It is normally difficult to extract from pulp and ends up a pollutant once it is removed. Most bioremediation technology is designed to remove a pollutant once it is generated or released into the environment although some types of bioremediation remove chemicals before they become pollutants.

Technologies using bioremediation treatment include bioaugmentation, biofilters, bioreactors, biostimulation, bioventing, composting and landfarming.

Bioaugmentation: This is a general term describing the addition of organisms or enzymes to a material to remove unwanted chemicals. Bioaugmentation is used to remove byproducts from raw materials and potential pollutants from waste. Bacteria are the most common bioaugmentation organisms. Many applications are accomplished using vegetation to remove excess nutrients, metals and pathogenic bacteria. Waste water from human and agricultural effluent is cleaned this way using wetland plants.

Biofilters: The removal of organic gases by passing air through compost or soil containing microorganisms capable of degrading the gases. It has been used to remove volatile organic compounds (VOC's) from air.

Bioreactors: The treatment of a contaminated substance in a large tank containing organisms or enzymes. Bioreactors are commonly used to remove toxic pollutants from solid waste and soil.

Biostimulation: The use of nutrients or substrates to stimulate the naturally occurring organisms that can perform bioremediation. Fertilizer and growth supplements are the common stimulant. The presence of small amounts of the pollutant can also act as a stimulant by turning on operons for the bioremediation enzymes.

Bioventing: This is similar to biostimulation. It involves the venting of oxygen through soil to stimulate the growth or natural and introduced bioremediation organisms. This is used predominantly for soils contaminated with petroleum products. It is not suitable for removing halogenated gases that contribute to ozone layer damage.

Composting: This involves mixing contaminated materials with compost containing

bioremediation organisms. The mixture incubates under aerobic and warm conditions. The resultant compost can be used as a soil augmentation or be placed in a sanitary landfill.

Landfarming: The use of farming tilling and soil amendment techniques to encourage the growth of bioremediation organisms in a contaminated area. It has been used successfully to remove large petroleum spills in soil.

These technologies are classified as either in situ or ex situ. In situ technologies are the ones commonly seen in the media. They involve the use of organisms or enzymes to remove pollutants in the location that is polluted. Ex situ technologies involve the removal of the contaminated material where it can be treated using bioremediation.

Limitations of Bioremediation

There are several limitations to bioremediation. One major limitation has to do with the nature of the organisms. The removal of pollutants by organisms is not a benevolent gesture. Rather, it is a strategy for survival. Most bioremediation organisms do their job under environmental conditions that suit their needs. Consequently, some type of environmental modification is needed to encourage the organisms to degrade or take up the pollutant at an acceptable rate. In many instances the organism must be presented with low levels of the pollutant over a period of time. This induces the organism to produce the metabolic pathways needed to digest the pollutant. When using bacteria and fungi, it is usually necessary to add fertilizer or oxygen to the material containing the pollutant. This can be disruptive to other organisms when done in situ. In situations where simple compounds and metals are being taken up it is likely that these pollutants are at toxic levels for the organisms. Overall, the organisms do not always live as well on the pollutant diet as on other nutrients found more commonly in their environment. This is problematical when doing in situ remediation.

Two other limitations concern cost/benefit ratios: cost versus overall environmental impact. Neither the government nor industry wants to spend large amounts of money to clean up pollution. Industry in particular likes to keep costs down. The petroleum industries are embroiled curretly in a battle with the EPA about the added costs of maintaining new Clean Air Act standards. Bioremediation is generally very costly, is labor intensive, and can take several months for the remediation to achieve acceptable levels. Air bioremediation in particular is very ineffecient, considering the volume of polluted air generated by industry. Another problem is that both ex situ and in situ technologies can cause environmental disruption beyond the damage done by the pollution. The long-term effects of introducing naturally occurring non-native bioremediation organisms into an area are not fully understood. The impact of genetically altered bioremediation organisms is even less understood.

The Reality of Bioremediation: A Panacea or a Fad? The question in the mind of many environmental scientists is, are the merits of bioremediation over-rated? Will bioremediation be a potential panacea for cleaning up the environment or will it prove to be impractical? Bioremediation has been proven to work effectively under laboratory conditions. Short-term studies show that it also works under several field conditions. Like many technologies with good scientific foundations its merits are marred by over-optimistic speculations and fraudulent claims. The Bioremediation Discussion List, hosted by GZA Environmental, Inc., provides evidence for the degree of specious claims that bioremediation specialists read in advertisements and trade journals. Bioremediation specialists argue over the reputed effectiveness of advertised "superbugs" that do a thorough cleanup in very little time. In spite of its limitations, bioremediation is benefitting from the rush to use biotechnology to solve public health problems. The EPA and the DOE are even investigating the feasibility of bioremediation to remove radioactive wastes from contaminated soil and water. Bioremediation's popularity is further enhanced because it is perceived as being more "green" than other remediation technologies. Companies and individuals are investing in biotechnology futures in spite of the high risks. As a result bioremediation companies have a viable future regardless of its long-term effectiveness.

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